

### Technical Field

This invention relates to the general subject of methods and apparatus for  
5 converting sunlight into electricity, and, in particular, to methods and apparatus used  
to display the performance of a photovoltaic power supply.

### CROSS-REFERENCE TO RELATED APPLICATIONS

10 This is a Patent Application claiming the priority of a USA Provisional Patent  
Application filed on April 4, 2003 under serial number 60/460,502 and entitled "PV  
Performance Monitor."

### STATEMENT REGARDING FEDERALLY - SPONSORED RESEARCH OR DEVELOPMENT

15

Not applicable

### REFERENCE TO A "MICROFICHE APPENDIX"

20

Not applicable

### Background of the Invention

25

The photovoltaic (PV) module is the basic building block of PV electrical  
systems. A PV module is composed of interconnected cells that are encapsulated  
between a glass cover and weatherproof backing. The modules are typically framed  
in aluminum frames suitable for mounting. The term "solar panel" is often used to  
refer to a PV module. However, the same expression is also used in reference to  
30 solar water heating systems, so to avoid confusion, "photovoltaic module" is

preferred.

The factors that affect the output of a solar power system should be understood so that a user has realistic expectations of overall system output and economic benefits under variable weather conditions over time. The amount of useful electricity generated by a PV module is directly generated to the intensity of light energy, which falls onto the conversion area. So, the greater the available solar resource, the greater is the electricity generation potential. The tropics, for instance, offer a better resource for generating electricity than is available at high latitudes. It also follows that a PV system will not generate electricity at night, and it is important that modules are not shaded. If electricity is required outside daylight hours, or if extended periods of bad weather are anticipated, some form of storage system is essential.

### **Material**

Among other things, the performance of a PV module depends on the cell material. The conversion efficiency of amorphous silicon modules varies from 6 to 8%. Modules of multi-crystalline silicon cells have a conversion efficiency of about 15%. Mono-crystalline silicon modules are the most efficient; their conversion efficiency is about 16%. Typical sizes of modules are 0.5 x 1.0 m<sup>2</sup> and 0.33 x 1.33 m<sup>2</sup>, made up of about 36 PV cells.

### **Standard Test Conditions**

Solar modules produce DC electricity. The DC output of solar modules is rated by manufacturers under Standard Test Conditions (STC). These conditions are easily recreated in a factory, and allow for consistent comparisons of products, but need to be modified to estimate output under common outdoor operating conditions. STC conditions are: solar cell temperature = 25° C; solar irradiance (intensity) = 1000 W/m<sup>2</sup> (often referred to as peak sunlight intensity, comparable to

clear summer noon time intensity); and solar spectrum as filtered by passing through 1.5 thickness of atmosphere (ASTM Standard Spectrum). A manufacturer may rate a particular solar module output at 100 Watts of power under STC, and call the product a "100-watt solar module." This module will often have a production  
5 tolerance of +/-5% of the rating, which means that the module can produce 95 Watts and still be called a "100-watt module." To be conservative, it is best to use the low end of the power output spectrum as a starting point (95 Watts for a 100-watt module). Fig. 1 is a graphical presentation of the current versus the voltage (I-V curve) from a photovoltaic cell as the load is increased from the short circuit (no load)  
10 condition to the open circuit (maximum voltage) condition. The shape of the curve characterizes cell performance; this can be called "factory performance" or performance of a PV cell under ideal conditions.

### **Spectrum**

15 The electrical current generated by photovoltaic devices is also influenced by the spectral distribution (spectrum) of sunlight. It is also commonly understood that the spectral distribution of sunlight varies during the day, being "redder" at sunrise and sunset and "bluer" at noon. The magnitude of the influence that the changing spectrum has on performance can vary significantly, depending on the photovoltaic  
20 technology being considered. In any case, spectral variation introduces a systematic influence on performance that is time-of-day dependent. Similarly, the optical characteristics of photovoltaic modules or pyranometer can result in a systematic influence on their performance related to the solar angle-of-incidence.

### **Temperature**

25 Module output power reduces as module temperature increases. When operating on a roof, a solar module will heat up substantially, reaching inner temperatures of 50 to 75 C degrees. For crystalline modules, a typical temperature

reduction factor recommended by the CEC is 89% or 0.89. Therefore, the “100-watt” module will typically operate at about 85 Watts ( $95 \text{ Watts} \times 0.89 = 85 \text{ Watts}$ ) in the middle of a spring or fall day, under full sunlight conditions. To ensure that PV modules do not overheat, it is essential that they be mounted in such a way as to allow air to move freely around them. This is a particularly important consideration in locations that are prone to extremely hot midday temperatures. The ideal PV generating conditions are cold, bright, sunny days.

#### **Dirt and dust**

Dirt and dust can accumulate on the solar module surface, blocking some of the sunlight and reducing output. Much of California has a rainy season and a dry season. Although typical dirt and dust is cleaned off during every rainy season, it is more realistic to estimate system output taking into account the reduction due to dust buildup in the dry season. A typical annual dust reduction factor to use is 93% or 0.93. Therefore, the “100-watt module,” operating with some accumulated dust may operate, on average, at about 79 Watts ( $85 \text{ Watts} \times 0.93 = 79 \text{ Watts}$ ).

#### **Mismatch and wiring losses**

The maximum power output of the total PV array is always less than the sum of the maximum output of the individual modules. This difference is a result of slight inconsistencies in performance from one module to the next, and is called “module mismatch” and can amount to at least a 2% loss in system power. Power is also lost to resistance in the system wiring. These losses should be kept to a minimum but it is often difficult to keep these losses below 3% for the system. A reasonable reduction factor for these losses is 95% or 0.95.

#### **DC to AC conversion losses**

The DC power generated by the solar module must be converted into

common household AC power using an inverter. Some power is lost in the conversion process, and there are additional losses in the wires from the rooftop array down to the inverter and out to the house panel. Modern inverters commonly used in residential PV power systems have peak efficiencies of 92% to 94% indicated by their manufacturers, but these again are measured under well-controlled factory conditions. Actual field conditions usually result in overall DC-to-AC conversion efficiencies of about 88% to 92%, with 90% or 0.90 a reasonable compromise. So the "100-watt module" output, reduced by production tolerance, heat, dust, wiring, AC conversion, and other losses should translate into about 68 Watts of AC power delivered to the house panel during the middle of a clear day (100 Watts x 0.95 x 0.89 x 0.93 x 0.95 x 0.90 = 67 Watts).

#### Estimating System Energy Output

In order to capture as solar energy as possible, the photovoltaic cell must be oriented towards the sun. If the photovoltaic cells have a fixed position, their orientation with respect to the south (northern hemisphere), and tilt angle, with respect to the horizontal plane, should be optimized. The optimum tilt angle lies within a range of approximately 15 degrees of the site latitude. For grid-connected PV systems in Western Europe, for instance, the optimum tilt angle is about 35 degrees. For regions nearer to the equator, this tilt angle will be smaller, and for regions nearer to the poles, it will be larger. A deviation of the tilt angle of 30 degrees from the optimum angle, will lead to less than 10% loss of the maximum yield. During the course of a day, the angle of sunlight striking the solar module will change, which will affect the power output. The output from the "100-watt module" will rise from zero gradually during dawn hours, and increase with the sun angle to its peak output at midday, and then gradually decrease into the afternoon and back down to zero at night. While this variation is due in part to the changing intensity of

the sun, the changing sun angle (relative to the modules) also has an effect

The pitch of the roof will affect the sun angle on the module surface, as will the East-West orientation of the roof. These effects are summarized in **Table 1**, which shows that an array on a 7:12-pitch roof facing due South in Southern California gives, for example, the greatest output (correction factor of 1.00), while an East facing roof at that same pitch would yield about 84% of the annual energy of the South facing roof (a correction factor of 0.84 from **Table 1**).

		<u>Flat</u>	<u>4:12</u>	<u>7:12</u>	<u>12:12</u>	<u>21:12</u>	<u>Vertical</u>
10	<b>South</b>	0.89	0.97	1.00	0.97	0.89	0.58
	<b>SSE, SSW</b>	0.89	0.97	0.99	0.96	0.88	0.59
	<b>SE, SW</b>	0.89	0.95	0.96	0.93	0.85	0.60
	<b>ESE, WSW</b>	0.89	0.92	0.91	0.87	0.79	0.57
	<b>E, W</b>	0.89	0.88	0.84	0.78	0.70	0.52

15 **TABLE 1: Orientation Factors for Various Roof Pitches and Directions**

	<u>CITY</u>	<u>kWh/kWstc (range)</u>
	<b>Arcata</b>	1092 - 1365
	<b>Shasta</b>	1345 - 1681
20	<b>San Francisco</b>	1379 - 1724
	<b>Sacramento</b>	1455 - 1819
	<b>Fresno</b>	1505 - 1881
	<b>Santa Maria</b>	1422 - 1778
	<b>Barstow</b>	1646 - 2058
25	<b>Los Angeles</b>	1406 - 1758
	<b>San Diego</b>	1406 - 1758

**TABLE 2: Annual Energy Production by City per kW STC array rating**

**Table 2** is intended to give a conservative estimate of the annual energy expected from a typical PV system, taking into account the various factors discussed above. These values are for annual kWh produced from a 1-kilowatt (1kW) STC DC array, as a simple and easy guide.

Example:

A 4 kW WSTC solar array (as specified under STC conditions) located in the Los Angeles area at a 4:12 pitch and facing southeast should produce at least 5343 kWh of electric energy annually ( $1406 \text{ kWh/kW} \times 0.95 \times 4 \text{ kW} = 5343 \text{ kWh}$ ). The typical residential customer in that area uses about 7300 kWh annually, meaning such a PV system could produce at least 75% of the total energy needed by such a typical home. Moreover, if energy efficiency measures were taken by the owner to reduce the overall electrical consumption of the home, the percentage could approach 100%. Note that the low end of the range was used to calculate the actual savings. It is wise to be conservative when making performance claims.

Maximum power output of most properly installed PV systems occurs near midday on sunny days in the spring and fall. If the owner fully understands this characteristic, they will not be disappointed with unavoidable low output in the middle of the winter. Metering is a way of proving to the owner that the equipment is properly installed. Often, the owner's primary indication of whether they feel the system is operating properly or not is their monthly electric bill. If the owner suddenly begins using more electricity, they may not see much decrease in their bill and assume the PV system is under-performing. Metering can help avoid disputes between the installer and the owner by showing that the system performs as advertised. One of the attractive attributes of PV system is low maintenance. However, even electrical systems need to be maintained from time to time. With proper metering, an informed owner can easily determine if their system is operating properly or not.

Previous methods (see Fig. 1) of checking the module and system performance often relied on "correcting back" from as-measured power to STC, usually by: using linear coefficients of  $dI_{sc}/dT$ ,  $dV_{oc}/dT$  and  $dP_{max}/dT$ , and

assuming a linear dependency on light level. However, when PV arrays are installed and used: during low light level periods (e.g. winter time), or during extreme temperatures, or during high solar incidence angles, then it is difficult to correct back to STC for the modules, as errors are largest when the biggest corrections in  
5 temperature and irradiance are made. It also has been difficult to check if the array was set up and performing as expected.

This problem has existed for some time. Considerable effort has been made, and significant amounts of money have been expended, to resolve this problem. In  
10 spite of this, the problem still exists. Actually, the problem has become aggravated with the passage of time because solar power systems are becoming more common and are being owned by consumers who do not know subtle solar engineering design factors.

### 15 Summary of the Invention

In accordance with the present invention, a method and apparatus is disclosed for monitoring the performance of a solar powered electrical supply for an electrical load wherein the supply comprises an array of photovoltaic cells that are mounted on a building and that have a predetermined performance. In one  
20 embodiment, the apparatus comprises: an irradiance sensor for producing a signal representative of solar irradiance; a circuit for deriving a running performance signal by using at least the irradiance signal and a measure of the electrical power supplied to the load from the array; a radio for broadcasting the performance signal; and a portable unit for receiving the performance signal from the radio and for visually  
25 displaying the performance of the solar electrical system.

In one embodiment, the portable unit comprises a plurality of indicators, including: solar irradiance, temperature, time, photovoltaic power production,



photovoltaic power relative to utility provided electrical power, photovoltaic power on a time scale, total photovoltaic power production, daily power production, power production relative to utility power consumption, and daily solar production relative to maximum possible production.

5

The invention analyses electrical grid connected PV system performance in real time to see if it is working correctly. In the event of a performance-limiting fault, it can send a signal to notify the user.

10

In another embodiment, the array is characterized by an outdoor temperature and the circuitry derives a running performance signal by using the irradiance signal, the predetermined performance rating of the array; and the measure of the electrical power supplied to the load from the array.

15

The invention provides an improved and efficient method and apparatus for owners of solar power systems to understand what is happening and how their system is performing. Numerous other advantages and features of the present invention will become readily apparent from the following detailed description of the invention, the embodiments described therein, from the claims, and from the accompanying drawings.

20

### Brief Description of the Drawings

FIG. 1 is a graphical depiction of current versus voltage from a PV cell as load is increased;

25

FIG. 2 is a block diagram of a typical solar electrical power system;

FIG. 3 is a schematic diagram of the Data Display Unit that is part of the subject invention;

FIG's. 4 and 5 are block diagrams of the components of two embodiments of

the present invention;

FIG. 6 is an alternative display of solar irradiance display of FIG 3; and

FIG. 7 is a partial assembly drawing of the Data Display Unit showing the bezel and liquid crystal display board coming together.

5

### Detailed Description

While this invention is susceptible of embodiment in many different forms, there is shown in the drawings, and will herein be described in detail, several specific  
10 embodiments of the invention. It should be understood, however, that the present disclosure is to be considered an exemplification of the principles of the invention and is not intended to limit the invention to any specific embodiment so described.

Before describing the invention in detail, the environment of the invention will  
15 be explained.

### Typical System Components:

A typical solar electrical power system (see Fig. 2) comprises: a PV Array, Balance of System Equipment, a DC to AC Inverter, and other components.

20

**PV Array:** Common PV modules are 5 to 25 square feet in size and weigh about 3 to 4 lbs./ft<sup>2</sup>. Often sets of four or more smaller modules are framed or attached together by struts in what is called a panel. This panel is typically around 20 to 35 square feet in area for ease of handling on a roof. This allows some  
25 assembly and wiring functions to be completed on the ground if called for by the installation instructions.

**DC-AC inverter:** This is a device that takes the DC power from the PV array and converts it into standard AC power used by the house appliances.

**Balance of System Equipment (BOS):** This refers to the mounting systems and wiring systems used to integrate the solar modules into the structural and electrical systems of the home. The wiring systems include disconnects for the DC and AC sides of the inverter, ground-fault protection, and over current protection for the solar modules. Most systems include a combiner board of some kind since most modules require fusing for each module source circuit. Some inverters include this fusing and combining function within the inverter enclosure.

**Other Components:** This may be dependent on the local utility and may include a utility switch.

### **Overview**

This invention, "PV-Verifier" or "PV<sup>2</sup>", defines a new way of checking the PV array performance:

- to help get the highest kWh out of a system,
- to maximise the usefulness, and
- to reduce the cost per kWh.

The invention is intended to monitor and display PV system performance. The present invention consists of two discrete units, interfaced by radio-frequency (RF) link:

- A Data Collection Unit 16 performs data measurement, processing, storage, and transmission via RF link to the Data Display Unit. Turning to Fig. 4, the data flow of the invention is depicted. The electrical load 10 of a building or other structure has electrical power provided to it from an external source 12 (e.g., an electrical utility, generator, battery, etc.) and from a solar PV power supply 14. The

Data Collection Unit 16 takes signals and information (e.g., from the power supply 14, the other power sources 12, factory performance characteristics of the array, etc.) and processes/converts that information into a format for broadcast by a relatively short-range radio 18. Circuitry for obtaining voltage, current, and power, and sending that information in a form suitable for further processing and transmission are known to those skilled in the art. The fixed Data Collection Unit 16 also includes signal processing circuitry 20, memory 22, clock 24 and an internal power supply (i.e., a battery, not shown for simplicity).

- The Data Display Unit 30 visually depicts information transmitted to it from the Data Collection Unit. The Data Display Unit 30 receives information broadcast from the radio 18 and converts that information into a format for visual display 32 (See Figures 3, 6, and 7). The portable Data Display Unit 30 also includes an internal power supply (i.e., a battery, not shown for simplicity).

- The RF interface is designed to function reliably through exterior and/or interior walls of the residence and at distances limited by the restrictions imposed by the FCC and the physical composition of the individual building or structure.

The Data Collection Unit 16 and the Data Display Unit 30 will now be described in greater detail.

### **Data Collection Unit**

This unit 16 has these functions:

- Measures true AC power out of PV system. Typically, 120V electrical service uses one current transducer located in electrical utility service entrance enclosure.

- Measures true AC power into and out of home at the service entrance. Standard 200 amp (A), Edison 3-wire 240 Vac residential utility service typically requires two current transducers.

- Measures solar irradiation using an analog sensor located by the  
5 solar PV array.

- Measures ambient temperature using a temperature sensor housed in an enclosure near the PV array.

Preferably, the sampling rate is consistent with refresh rate on Display Unit. A voltage transducer is used for power measurement (i.e., monitor either  
10 line-to-line 240Vac or one 120 Vac leg). Current transducers for home power measurement may be the "split type" for ease of installation.

The Data Collection Unit 16 may be provided with a RS-232 port to facilitate setup/calibration. Depending on available memory, averaged data may be stored  
15 several times each hour. Preferably, on-board memory retains data up to 30 days, the data is time and date stamped, and calibration, data and clock settings are stored in non-volatile memory.

Preferably the Data Collection Unit 16 is designed to function without an on-board modem. The unit may be provided with space and functionality if a modem is  
20 subsequently installed (i.e., adoption of modem feature without redesign of product, by providing a socket in base design). If used, these matters may be considered:

- Data is identified by site code.
  - Dials out daily to a pre-set number or ISP for upload of data to host database.
  - Desired dial out schedule is set by host.
  - Modem and data transmission speed are consistent with a short transmission time.
- 25

- Dial out transmission should drop out if homeowner picks up telephone to make call.
- Dropped-out transmissions should be re-attempted after dial tone is detected.
- 5      • Data storage in the event of phone problems or other interruptions.
- Unit clock is reset by host during dial out transmission.

Preferably, the specifications on the Data Collection Unit 16 would include:

- outdoor rated, and non-metallic.
- 10      • appearance is consistent with other residential service entrance enclosures.
- corrosion resistant finish consistent with long life in outdoor environment.
- mechanical configuration permits all power measurement inputs and  
15      unit power to be routed from household service entrance through a single conduit.
- tamper resistant.
- internal components are protected from condensation and/or internal heat generation.
- 20      • inverter independent.
- temperature and irradiance inputs that are routed from roof via a multi-conductor cable and a cable gland.
- optional phone cable for option modem is routed via cable gland.
- power to operate the unit is supplied from AC source in utility service  
25      entrance; function may be combined with voltage transducer required for power measurement.
- operates over the expected range of temperatures of the geographic

area.

- operates over the expected range of relative humidity of the geographic area.
- inputs are protected against electrical/lightning-induced surges.
- antenna is otherwise protected from mechanical damage.
- contains battery-backed real-time clock/calendar that has high lifetime accuracy and that is settable without opening enclosure .

### Display Unit

The Data Display Unit 30 receives data wirelessly from the Data Collection Unit 16. The wireless feature can be achieved by using conventional radio frequencies, cell-phone frequencies, wireless networking, Bluetooth® wireless technology, text messaging and optical infrared. Preferably, the unit has these features:

- No visible antenna.
- Portable.
- Installs in the interior of the building (e.g., hangs on the wall).
- Battery power (no external wire connections) expected minimum battery lifetime of at least several months.
- No user accessible switches or controls.
- Display layout per Fig. 3 and/or Fig. 6.
- Injection-molded enclosure (see Fig. 7).
- Frequent refresh interval.
- Viewable display dimensions about 2" x 7".

Preferably, the Data Display Unit 30 includes "Sunlight Intensity Icons" 50. This is a display of solar irradiance. It is the approximate intensity of the sunlight at the array. As shown in the drawings, four different sized "suns" arrayed left to right,

smallest to largest, with intensity as a percentage to the far right:

- ◆ 0% to 15% blank;
- ◆ 15% to 25% 1<sup>st</sup> sun (smallest);
- ◆ 25% to 50% 2<sup>nd</sup> sun;
- ◆ 50% to 75% 3<sup>rd</sup> sun; and
- ◆ 75% to 100% 4<sup>th</sup> sun (largest or highest irradiance).

No “suns” are displayed at night or on overcast days and all suns are shown at full sunlight intensity. Fig. 6 is an alternative display for solar irradiance. Here solar irradiance is displayed as a percentage of maximum 51 and in the form of “sun icons.”

#### **Data Processing, Storage and Transmission:**

Data transmission to Data Display Unit 30 is performed wirelessly. Referring to Fig. 3, the data displayed would include:

**Solar Production:** This is a display 52 of the amount of power (kW) the solar electric system is currently producing.,

**Household Usage:** This is a display 54 of the amount of power (kW) the residence is using right now (i.e., sum of PV service and electrical utility service entrance measurements),

**Demand Met by Solar:** This is a display 56 of the percentage of the home’s electricity that is generated by the solar electric system,

**Outdoor temperature:** This is a display 58 in deg F or deg C (preferably, software settable),

**Daily Solar Production:** This is a display 59 amount of energy (kWh) the solar electric system produced over the current calendar day,

**Daily Demand Met by Solar:** This is a display 60 of the percentage of electrical energy consumed (i.e., household consumption) since 12:01 AM for the current day and produced by the solar electric system. It starts at 0% immediately



after midnight and increase as the day progresses. When the sun sets, this value will decrease while power is used in the home,

**Capacity Bar Graph:** This is a graphic representation 62 of today's solar electricity production hour-by-hour. In this embodiment the day's energy production is graphed from 6 AM until 6 PM. It helps the user know energy was produced during the day,

**Time:** This is a display 64 of local time in AM/PM or 24 hr (preferably, software settable,

**Total Solar Production:** This is a display 66 of the cumulative energy (kWh) produced by the solar electric system since it was installed.,

**System Status:** If the Data Display Unit 32 is outside transmission range the Data Collection Unit 16, or solar power production is lower than expected, "check system" light 68 will appear. Normally a system "OK" will be displayed. The objective is to detect if the output of electricity from the PV power supply is consistent with the output expected when the intensity of the sun (irradiance) is considered.

#### General Preferences

Preferably, in the United States, the equipment would have these features:

- Underwriters Laboratory (UL) listed or recognized.
- Meets FCC requirements.
- Design tested and/or evaluated for proper operation in a household environment with no interference with other household electronic devices.
- Installed in compliance with local electric codes.
- Designed and constructed to have a long life.
- Free from defects in material, workmanship, and function from the date of purchase.

### Operation and Performance

On start-up, the PV<sup>2</sup> reads, from memory: values of PV parameters (See Fig. 1), such as: Pmax.stc (and if available), Vmax.stc, and Imax.stc), and system constants, such as:

- the percentage (i.e., 50%) of calculated power the system must achieve in order to pass the system status test, and
- the minimum signal (i.e., radio wireless) strength that must be received by the display unit to provide reliable operation, and
- the threshold light intensity below which the pass/fail criteria will not be checked).

Next, it loads typical empirical coefficients for determining the likely array output as a function of instantaneous Irradiance. The maximum expected clear sky irradiance on the array can be inferred from  $T_{\text{ambient}}$ , clock time, latitude and longitude of the array, and array orientation (azimuth and tilt). If the Vdc and Idc are known, then these can be checked against input limits and empirical equations to make sure the system is tracking properly. If the irradiance is above a pre-defined threshold, then the system calculates the expected output power from an empirical equation. Alternatively, and more simply, an instantaneous Irradiance signal can be used alone to compare against the measured power out of the solar array, and if the difference between measured power and the expected output exceeds a pre-determined amount (e.g., 50%) the System Status light 68 would be lighted. This would show that the array is not properly performing, or that the radio signal from the Data Collection Unit 16 to the Data Display Unit 32 is too weak for reliable data transfer.

The following is an example of the coding to perform this assessment:

```

5      // Define constants
      Pmax = 10 // kWp
      A = 0.8
      B = 0.1
      C = -0.0045
      E = 1
10     Fail = 0.5 // you need at least this to pass
      Dark = 0.2 // suns
      Fails_in_a_row = 5

      // Every measurement
15     Get Gi // solar irradiance
      Get Tam // ambient temperature
      Get Pac // measured AC power output Pac

      Ycalc = Gi * (A + B*Gi + C*Tam) - E
20     //Check Gi, Tam, Pac are valid

      If Gi > Dark
          If Pac/Pmax < Ycalc * Fail then
25             Fails++
                Passes = 0
                If Fails >> Fails_in_a_row then SYSTEM DOWN
          else
30             Passes++
                Fails = 0
                If Passes >> Fails_in_a_row then SYSTEM BACK ON

```

This occupies just a couple of kB of code.  $C \cdot T_{am}$  can be interpreted as a thermal de-rating factor (e.g.,  $-0.5\%/^{\circ}\text{C}$ ). “A” is a linear parameter that dominates the computation (e.g., about 0.8 to 1.0). “B” is a non-linear parameter. “E” is a term representing a constant loss. Adding a term for wind speed can further refine performance prediction.

From the foregoing description, it will be observed that numerous variations, alternatives, and modifications will be apparent to those skilled in the art. Accordingly, this description is to be construed as illustrative only and is for the purpose of teaching those skilled in the art the manner of carrying out the invention. Various changes may be made in the shape, materials, size and arrangement of parts. For example, a generally rectangular tall display is shown in Fig. 3; a

generally horizontal display may be used as well. Moreover, equivalent elements may be substituted for those illustrated and described. Parts may be reversed and certain features of the invention may be used independently of other features of the invention. As another example, the more complex functional block diagram of Fig. 5  
5 may be used. In that illustration, the geometry of the array (i.e., tilt and azimuth) as well as the geographic location of the array and irradiance are taken into consideration in deriving a signal representative of the expected output of the solar power supply. As yet another example, the clock in the fixed unit may drift away from true time and not be correctly set to solar time. The shape of the daily  
10 irradiance curve may be used to calculate solar dawn, noon, and dusk. These values can be stored in memory and compared to when dusk, noon and dawn are predicted based on an ephemeris located in memory. When appropriate, the clock can be adjusted to solar time. Alternately, one could use an "atomic clock" tuned to a central observatory. One could also store daily sums of irradiance, ambient  
15 temperature and AC power output. That would only take a kB or so of memory and then build up daily performances, like above, without worrying about low light levels, etc. Once you have enough data, you could do some linear regression/curve fitting. Linear regression should not take too much memory. As a final example, you could also store a day of 15-minute data and a month of daily sum data. You could  
20 multiply everything by 100 and store as integers to reduce code and memory requirements. The system could also be set up to calculate daily averages and send these to a central site, or to store monthly averages to enable data interrogation via modem line. The effect of shadowing or problems such as inverter start-up in the morning can be determined by the system analysing: the shapes of the irradiance  
25 (time of day, month) and yield (time of day, month) arrays. If the system had been working, then a predefined succession of failures will flag an error signal that will be sent to an engineer. Similarly if the array comes back on line then a succession of

pass measurements will cause a pass signal to be sent. The invention provides the model from actual measured data. One can start out by using the data from a system that uses similar hardware for validation, but you can soon switch to using past data from the system itself to check performance. Thus, it will be appreciated  
5 that various modifications, alternatives, variations, and changes may be made without departing from the spirit and scope of the invention as defined in the appended claims. For example, although the invention is described in a solar context, the basic principles are applicable to other forms of alternative electrical supply systems (e.g., wind power and microhydro) that augment electrical utilities. It  
10 is, of course, intended to cover by the appended claims all such modifications involved within the scope of the claims.